Hydro-Electric Generation System for the DC House Project

Dennis Kwan

Mitchel Krug

Senior Project

Advisor: Professor Taufik

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

San Luis Obispo

2011

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I want to thank my parents for supporting me financially and emotionally throughout this project. I also want to thank Professor Taufik for his time and commitment to make this project possible.

-Dennis Kwan

First off, I would like to thank my family. All their support and encouragement have taken me this far. Without them, I don't know where I would be right now.

I want to thank Dr. Taufik and the entire EE department. For these past 5 years, they have been my mentors. I thank you for taking the time to work with all us and help us create our own futures.

-Mitchell

ABSTRACT

This paper focuses on the design, integration, and construction of a system that harnesses energy from flowing water. The system will be used in conjunction with the DC House Project. The proposed system employs a DC generator and DC-DC Boost-converter to provide electricity to the DC House at approximately 200-300W. Results of the testing and measurement show that the goal of the system is feasible, but currently limited. The generator could not output the specified power. Details of the design along with ideas for further improvement are presented in this report.

I. Introduction

Renewable energy has been widely adopted for its reusable source of energy that is naturally replenished. Different basic types of renewable energy consist of wind from the air, water from rivers/streams, and solar energy (photovoltaic) from the sun. These natural resources are created by complex chemical reactions of the universe, providing earth with these abundant resources. Renewable energy is clean and effortless, making it the better choice versus nuclear, steam, coal or fuel power plants. The world is currently using renewables as seen in Figure 1-1.

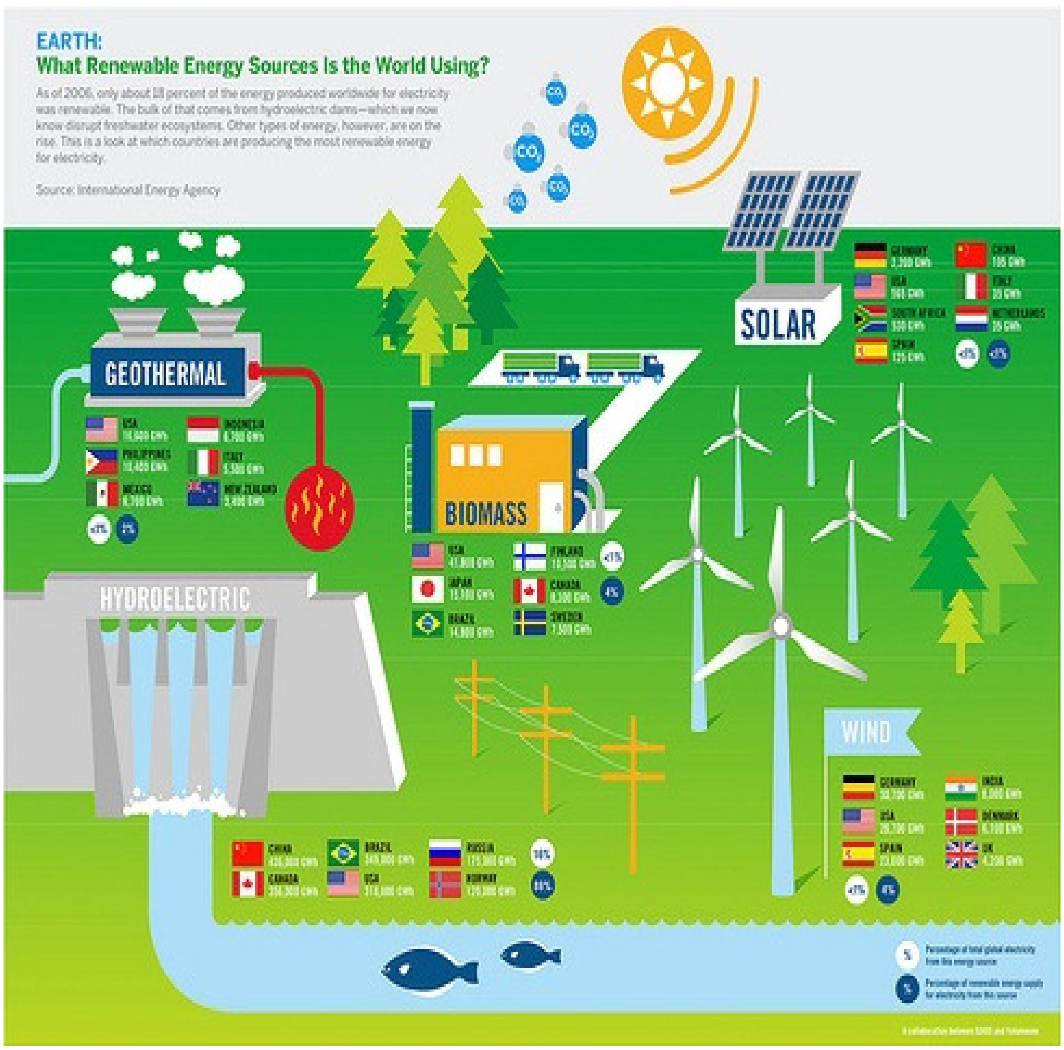

Figure 1-1. Renewable Energy Sources the World is Currently Using

Hydropower is the energy that comes from the force of moving water [1]. Harnessing the power of water has dated to the time of ancient Mesopotamia and Egypt when irrigation systems easily transported water to keep land fertile as depicted in Figure 1-2.

Figure 1-2. Representation of Ancient Irrigation System

Imperial Rome used the watermill to effectively grind grain and produce flour as shown in Figure 1-3. Ancient civilizations understood the importance of harnessing this renewable source of energy to improve the quality and ease of living.

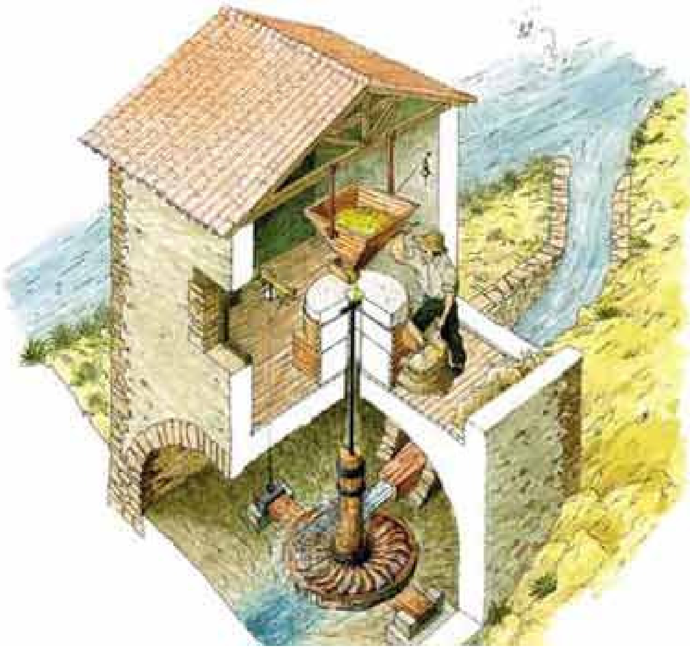

Figure 1-3. Grain Mill Using Hydro-power

In 1831, Michael Faraday devised experiments, using his “induction ring,” as shown in Figure 1-4, and rotation, to produce a steady current of electricity [2]. Faraday’s experiments led to the development of an electrical generator. By the late 19th century, the electrical generator could be coupled with water to power a house.

Figure 1-4. Michael Faraday's Induction Ring

In the early part of 20th century, the USA approved several major damming projects, including the Hoover and Roosevelt dam [2]. This ushered in the use of a renewable energy. Today, most rivers in the U.S. implement some form of a dam to produce power for distribution in neighboring areas. A depiction of a dam system can be seen in Figure 1-5.

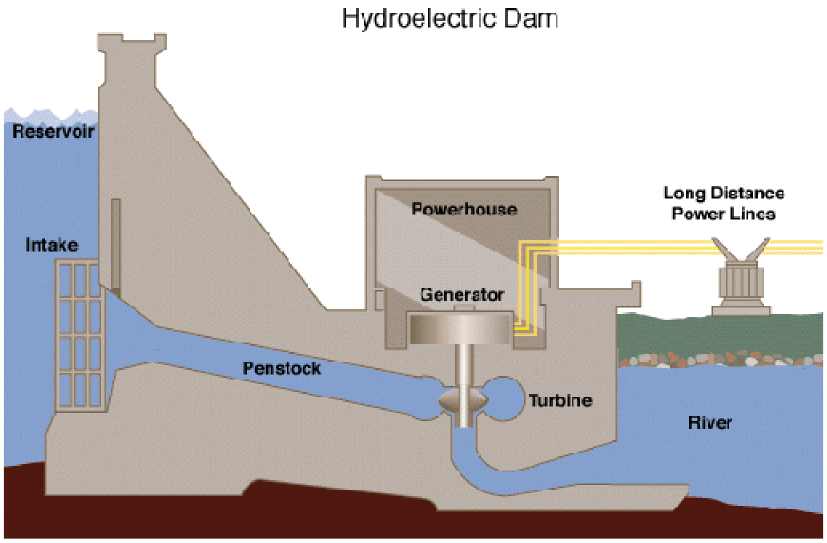

Figure 1-5. Hydroelectric Dam System

The advantage of hydroelectric systems over other renewable energies is that it has longer economic lives [5]. Another advantage that the hydroelectric system has is that the output is more predictable than wind or solar energy, as the level of wind force and sunlight intensity depends on the climate and time of day, respectively. The disadvantage of hydroelectric systems is that they must be constructed or placed in an area where there is water available. The locations of wind farms and solar farms in the other hand are more flexible.

With the world moving towards more eco-friendly means of energy production, comes the need for developing efficient forms of harnessing renewables. It is the desire of many organizations to wean people away from the everyday use of fossil fuels and towards sustainability. New technology is researched everyday so that renewable forms of energy can be efficiently and effectively distributed. As represented in Figure 1-6, hydropower is the most common form of renewable energy used.

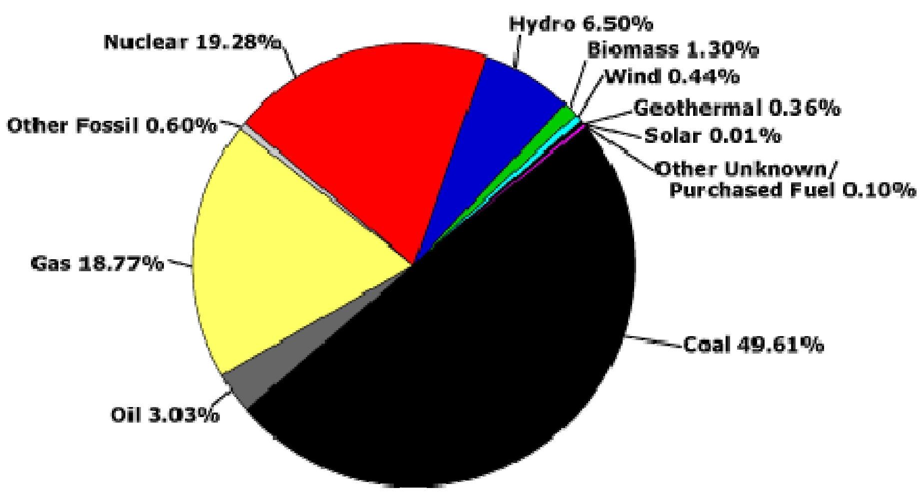

Figure 6 - Power Production in the United States for 2009

II. Background

Electricity is constantly improving the daily lives of the world. From something as simple as turning on a light bulb, charging a cellular phone, or microwaving food, the demand for electricity is everywhere. In the US, electricity is high in demand as electricity has become a large part of a person's daily life. People in the US are fortunate to have the resources to produce high levels of electricity to supply their high wattage luxuries.

People in remote and secluded islands are not as fortunate as it is difficult and economically unreasonable to transmit power to the area. The demand for electricity in remote and secluded islands is not high enough to build a large centralized power plant. The limited amount of land on a secluded island makes building a power plant undesirable and underdeveloped countries cannot afford to build one. The total number of individuals without electric power is put at about 1.6 billion, or a quarter of the world's population, concentrated mostly in Africa and southern Asia [3]. An alternative solution to improving the living conditions of people that live in these places is the DC House.

The DC House is a multi-team, collaborative project, with the overall goal of bringing DC power to people where an electrical grid is inaccessible or not desirable [4]. Phase 1 of the project is set to finish at the end of the 2010-2011 Cal Poly school year with a total of eight teams developing the house design, power production, and power distribution of the DC House [4]. The work, in question, is all being done in the hopes that one day mass production of the DC House will occur, bringing electricity to some of the 1.6 billion people in the world without it, thus improving the quality of living [4].

The Hydro-Generator Design is just one of the four projects currently in development that will produce power for the DC House. The main goal of the Hydro-Generator Project is to take the renewable energy of water, design a system to produce DC power, and efficiently transmit that power to the DC House.

III. Requirements

The overall hydro-generator project needs to meet three major requirements: portability, cost, and production.

The generator and accompanying equipment must be small enough that one person or a small group or people can move it from one place to another. The reason why the hydroelectric system needs to be portable is because it allows the owner to protect their system by retrieving it when weather conditions can potentially harm the system in any manner. The portability of the system is also beneficial if the flow of water is faster at a different location, which would increase the output voltage of the system. It is also convenient to have a portable system if one is to permanently relocate.

The output of the generator is produced mainly through torque rather than the speed of rotation of the shaft. The system is designed to provide an output voltage of 24V at 200W-300W to operate loads that represent basic necessities. A few examples of loads that improve living conditions include light bulbs for visibility in the house at night, electric stoves to cook food without having to start a fire, and portable heaters to keep warm during cold winter nights.

The overall design must be cheap enough for mass production. Since the hydroelectric system should be portable, and the output voltage is only 24V, the price of the system is affordable. The most expensive equipment of the system is the 12V input to 24V output DC-DC converter. Each hydroelectric system should be around the price range of $300-$400, which should be less if mass-produced.

IV. Design

The overall design of the project is to have running water freely spin a turbine attached to a DC generator. The specifications require a constant output of 24V at 200-300W. In order to achieve this desired output, we decided that it is necessary to attach the output of the generator to a DC-DC boost-converter. The reason behind using a DC-DC boost-converter in the first place is because we predict that the speed of running water itself will not be able to spin the turbine at the necessary RPMs to produce 24V. The characteristics of a boost-converter can also help us maintain a steady output of 24V for a wide range of voltage inputs due to the varying RPM from the flowing water.

In the early stages of our project, we considered the idea of building every hardware component of the system design. We initially believed that this approach of building the hardware would prove to be cost-effective, and in the process learn more about what goes into each component. When researching the process to build each component, we found that we did not have the time and resources to construct efficient products.

The construction of an efficient water turbine requires a symmetrical, balanced, and durable design. The operation of a water turbine is that flowing water hits the blades, spinning the runner, and creating kinetic energy. The turbine should run for a long period of time with minor maintenance. Symmetry, balance, and durability all factor in to the longevity of the turbine. A symmetrical wheel and blades will distribute water pressure evenly during operation. A balanced turbine will maximize efficiency of the entire system. Durability of the material will reduce normal wear and tear during normal operation. Meeting these specifications requires machining processes with materials that are not readily accessible to meet our needs. Figure 4-1 shows the different types of commonly used turbine designs.

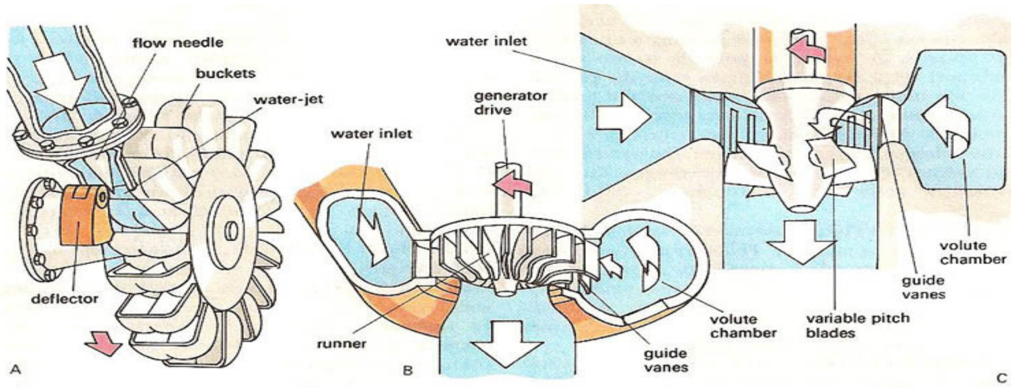

Figure 4-1. Typical Turbines: (A) Pelton Turbine, (B) Francis Turbine, (C) Kaplan Turbine

In the course of our studies, we have learned the theoretical operation of DC generators. A DC generator consists of two poles that create a magnetic field. An armature is a cylindrical core wound by copper coils. The armature is spun through an external source, i.e. our water turbine. This spinning of the armature works in conjunction with the magnets to produce a current. The basic construction and operation of a DC generator is depicted in Figure 4-2.

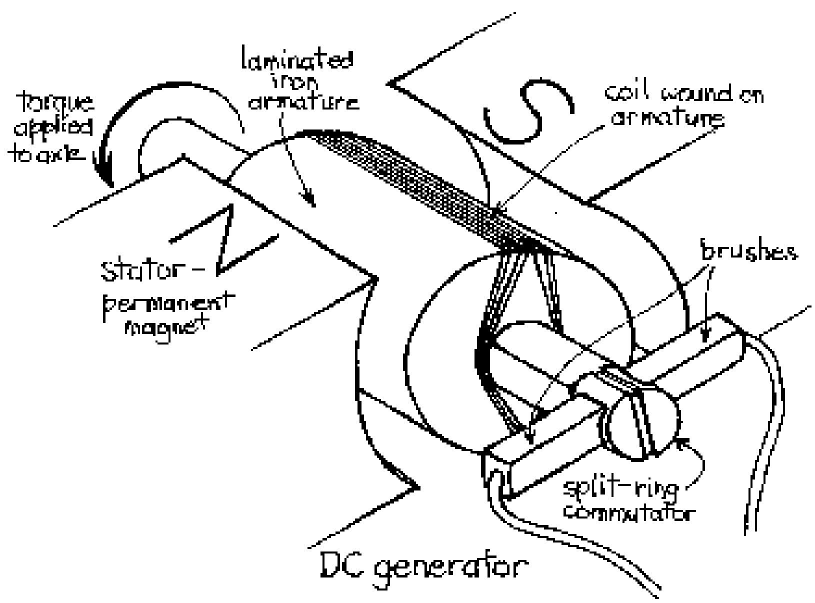

Figure 4-2. Basic Structure of a DC Generator

The generator's efficiency depends highly on the symmetry, balance, and quality of individual components within the overall generator. Similar to the problems of building a turbine, we do not have the machining processes or materials to meet the requirements to build an efficient generator.

Creating a DC-DC boost-converter seemed to be the most feasible component to construct with our knowledge in power electronics. The basic operation of a DC-DC boost-converter is to step up the input DC voltage to a higher output DC voltage. In Figure 4-3, a basic DC-DC boost-converter circuit is shown.

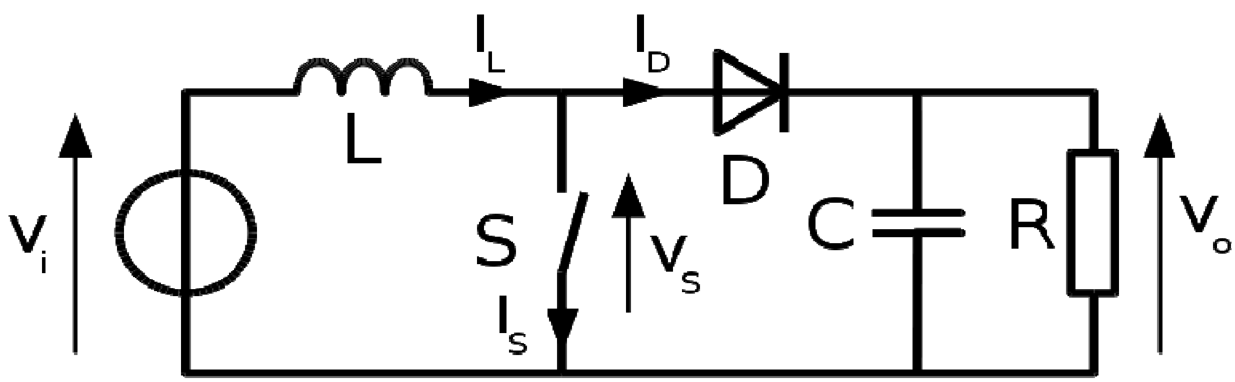

Figure 4-3. Basic Circuit of DC-DC Boost-converter

When the switch is on, the only path of the current is through the inductor and back to the source, charging the inductor current. When the switch is off, the diode is conducting, allowing the output voltage to be the voltage of the inductor. The accumulated energy in the inductor while the switch was on is transferred to the output. Since the voltage of the inductor is the product of the change in current and the inductor value, the voltage of the inductor can be greater than the input voltage. There are two ways to increase the voltage of the inductor. One can either increase the size of the inductor or increase the rate of change in current of the inductor. The problem with creating our own boost-converter is that the component ratings are fairly high for our design specifications. The boost-converter created in our course studies had much lower output specifications that require much lower component ratings. The task of maintaining a low voltage and line regulation for our converter for this project will be very difficult due to the fact that we have experienced difficulties with a lower rated converter.

With the given amount of time to complete this project, we concluded that it is not realistic to build any of these components. If we were to construct these parts, it would take away the main purpose of the project of piecing a sustainable, reliable, and portable hydro-electric generation system together. We researched for components that met our specifications and purchased them at the lowest price possible. It is important that the system is within a reasonable initial cost so that it is affordable.

After researching different types of small turbines for purchase we found the Pelton Wheel shown in Figure 4-4 to be the most ideal option for our overall system.

Figure 4-4. Pelton Turbine

In Figure 4-5, the dimensions of the turbine is shown, which is a reasonable size for portability's sake.

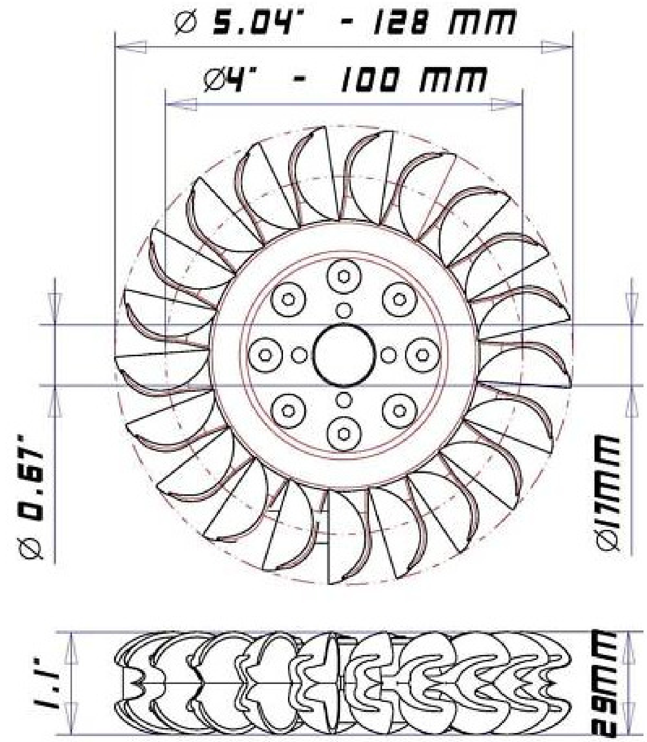

Figure 4-5. Pelton Turbine Dimensions

After doing research, the Pelton Wheel is one the most efficient design since the early inceptions of turbines in the early 19th century. Most early turbines had a design in which water will enter at high speed and leave at high speed. This meant that most of the energy of the water was not transferred into the turbine itself. In 1879, Lester Allan Pelton created a design that would have water enter at high speed and leave at very little speed, meaning the water transfers most of its kinetic energy to the wheel. The design is shown in Figure 4-6.

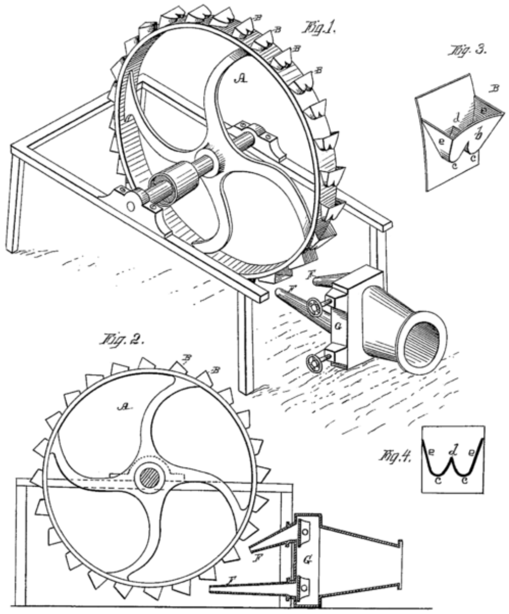

Figure 4-6. Lester Allan Pelton 1880 Patent

Today, the Pelton turbine can achieve up to 92% efficiency [5]. Figure 4-7 shows a modern Pelton turbine in use. This fact alone gave us enough purpose to purchase the turbine instead of designing and building our own. It is our hope that this efficient design will transfer into our overall hydro-electric generation system.

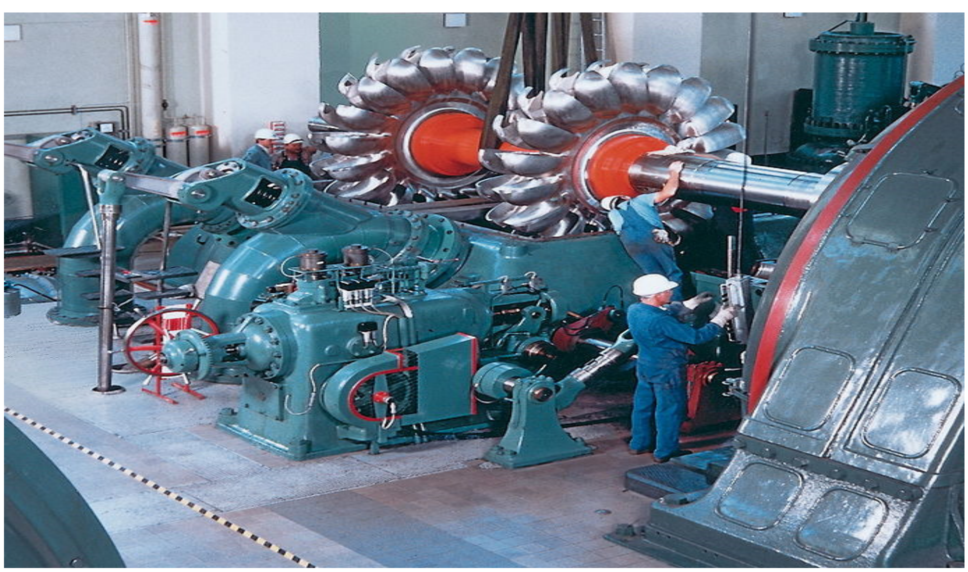

Figure 4-7. Modern Pelton Turbine in Use

When considering purchasing our DC generator, we aimed to look for low-speed and high-torque. During the researching process, we found that using a treadmill motor will be the best way to harness sustainable energy, whether it is water or wind. The size of a treadmill motor makes it ideal for our portability purposes. Figure 4-8 shows the generator that we purchased.

Figure 4-8. DC Generator

This was the best generator we found at the cheapest price because it had the highest current to RPM ratio. Figure 4-9 shows the nameplate ratings of the motor.

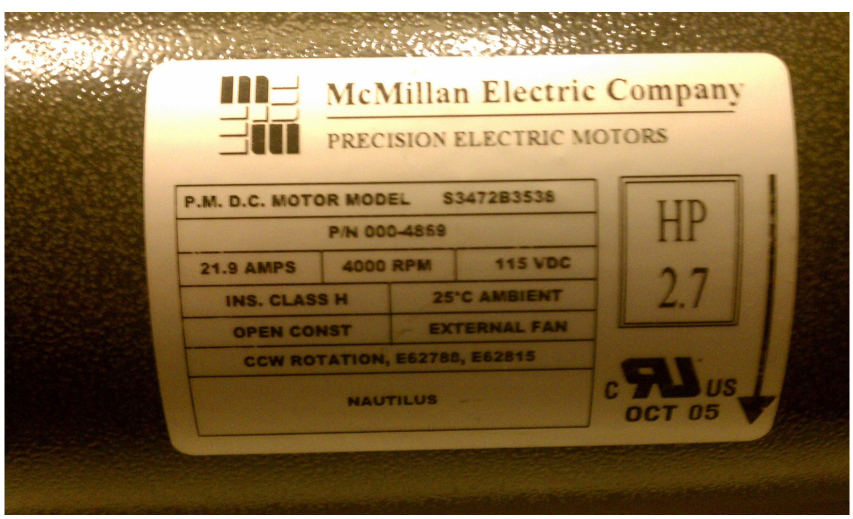

Figure 4-9. DC Generator Nameplate Ratings

This motor is relatively heavy, about 40 lbs., but can be lifted with one or two people. This task will be made easier if placed in a case with handles. Figures 4-10 and 4-11 show the dimensions. Although the motor is heavy, it is portable with a proper carrying case.

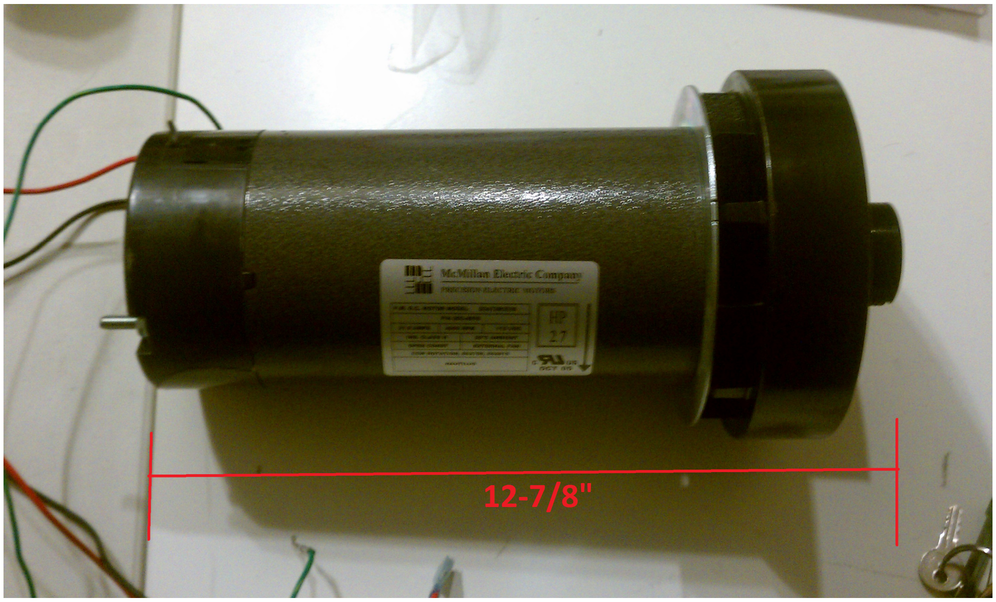

Figure 4-10. DC Generator Length

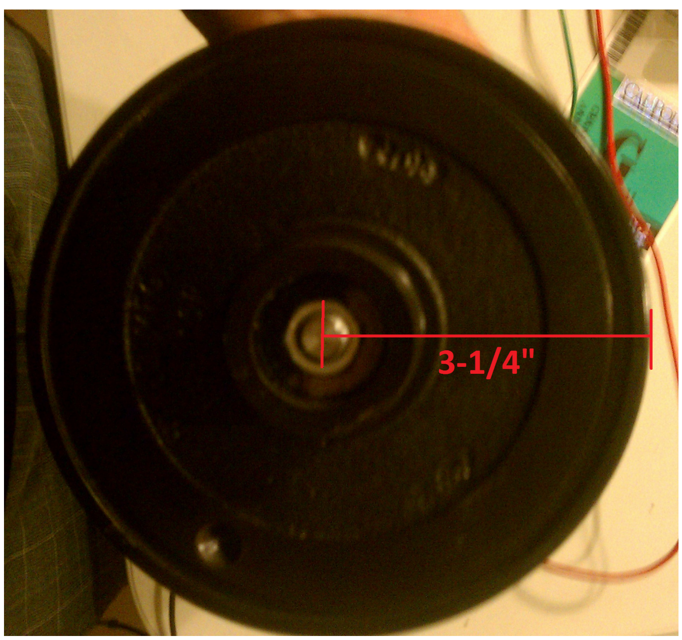

Figure 4-11. DC Generator Face Radius

When considering the purchase of a DC-DC boost-converter, we needed to meet the constant output of 24V at 200-300W output specifications. After researching several options, we found a 12V in/ 24V out/ 300W DC-DC boost-converter. Figure 4-12 shows the converter that we purchased.

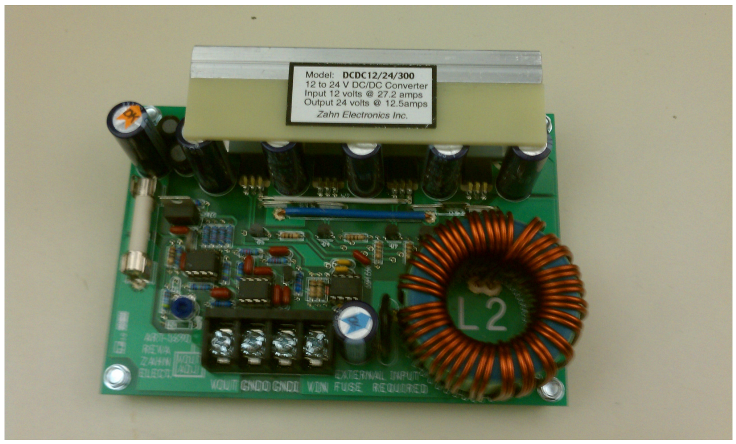

Figure 4-12. DC-DC Boost-converter

Figure 4-13 shows the dimensions of the converter. The overall area of the DC-DC Boost-converter is 23.2 in^2. The design is small and therefore meets our portability requirement.

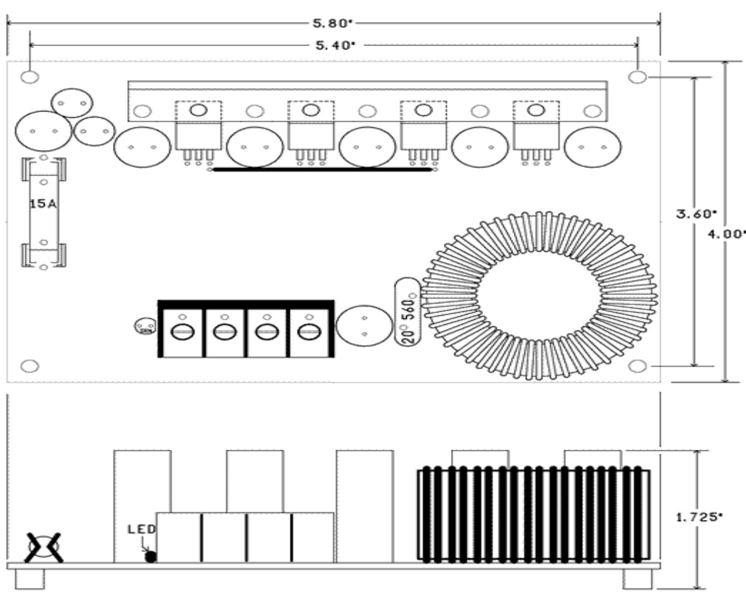

Figure 4-13. Top and Side View Dimensions of DC-DC Boost-converter

The black box diagram in Figure 4-14 shows the representation of the overall system design. A physical representation of a hydro-electric generator system is shown in Figure 4-15. We envisioned our system to look similar to Figure 4-15, but on a much smaller scale.

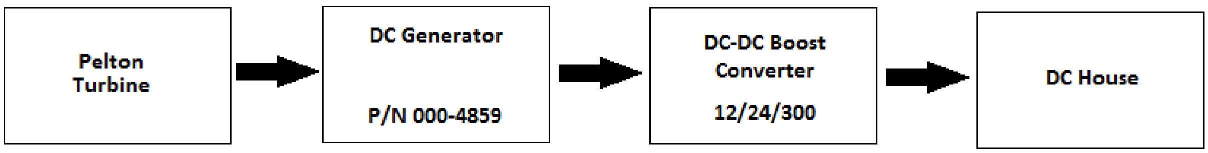

Figure 4-14. Black Box Diagram of Overall System

Figure 4-15. Larger Representation of Envisioned Design

V. Test Plans

For the first phase of our testing we plan to test the output voltage of our generator. We are planning to use an induction motor to rotate our generator, which in turn, should produce an output voltage. We are controlling the speed through an Adjustable Speed Drive (ASD). Using the motor speed indicator in lab, we should be able to get an idea of how much voltage the generator can produce at certain RPM values. The purpose of extracting this data is to predict how fast the water needs to flow in order to produce certain voltages. Figure 5-1 shows the block diagram of this test setup.

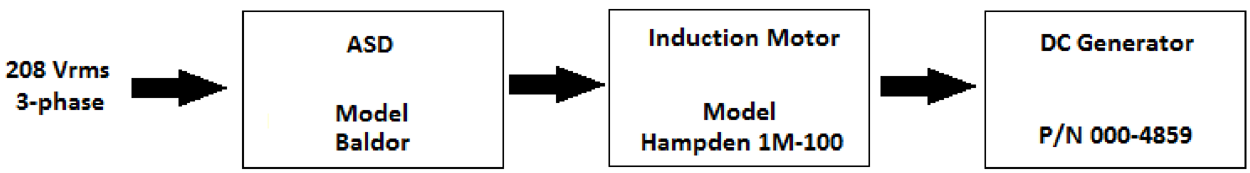

Figure 5-1. Block Diagram of Test Setup

The second phase of our testing is to test the output voltage of our DC-DC boost-converter with no load. We expect our boost-converter to output 24V when given an input of 12V. With our expectations, we should meet our voltage specifications. The next step of testing in our second phase is to test our converter with different loads to determine overall converter's efficiency. We plan to use an electronic load at the output of the converter and record the power characteristics of the output of the system at various RPM values. This test also enables us to measure line and load regulations of the converter. Figure 5-2 shows the test setup.

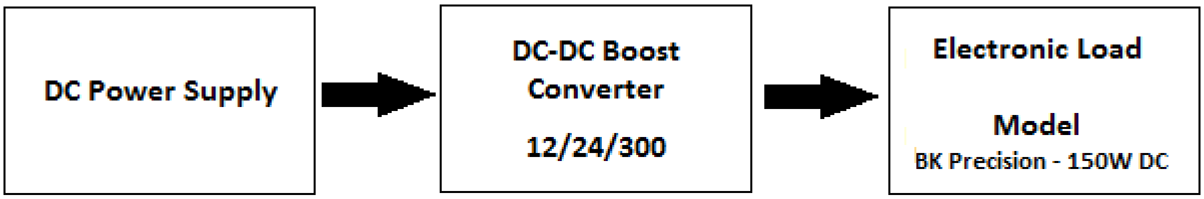

Figure 5-2. Block Diagram of Test Setup for Line and Load Regulation

VI. Development and Construction

In order to integrate the generator to the induction motor, a base board and the proper coupling is necessary to insure safe and reliable test results. The base board is designed to align the armature of the generator to the armature of the induction motor. The base board should also lock-in to the test bench, to prevent damage to both the generator and motor. Damages can occur if there is any displacement of the armatures while testing. A coupling is required, because the head of the motor cannot directly connect to the head of the generator.

To create a compatible base board for our generator, we used the base board of the DC drive as our template because it is the same height as the induction motor. As seen in Figure 6-1 and Figure 6-2, the length of the base board is 14” and the height of the center of the DC drive is 4”, respectively.

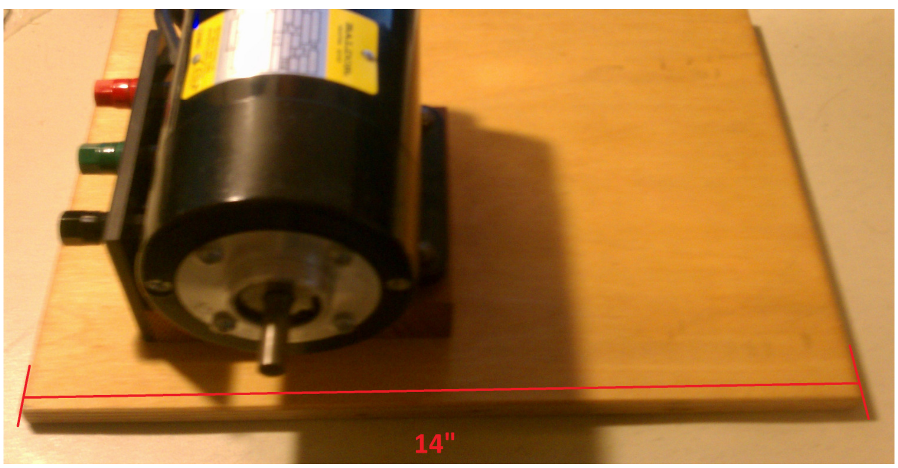

Figure 6-1. DC Drive Base Board Length

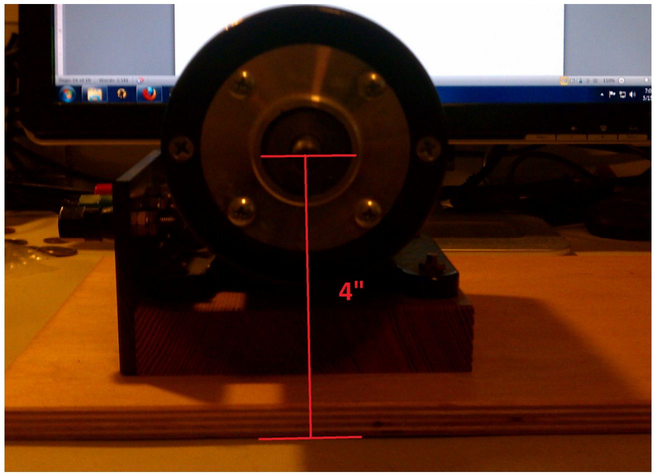

Figure 6-2. DC Drive Height

Figure 6-3 shows that the radius of the body of our motor is 2 ¼”. It is therefore necessary to raise our generator by 1 ¾” from the surface to ensure proper alignment for the coupling.

Figure 6-3. DC Generator Body Radius

To ensure proper lift and stability during testing, we designed a stand out of wood that has similar dimensions to the DC drive’s base length and height, as shown in Figure 6-4.

Figure 6-4. DC Generator Stand Used for Testing

Since we did not want to alter the generator in any way, we had to develop a type of coupling to hold the connector seen in Figure 6-5.

Figure 6-5. Connector for Generator and DC Drive Integration

Figure 6-6 shows the head of the generator. The head itself has grooves that make it difficult to directly attach the connector as seen in the previous figures. Therefore, we needed to develop a piece that can be tightly attached to the generator at one end and the connector on the other. The best method we found to hold the connector was to use a short PVC pipe. The best method to integrate the PVC pipe to the generator was a PVC rubber connector. Figures 6-7 and 6-8 show the PVC pipe holding the connector.

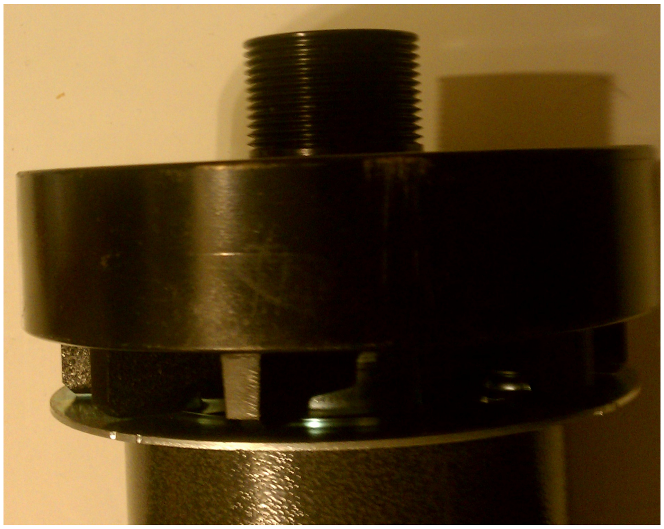

Figure 6-6. DC Generator Head

Figure 6-7. Connector Attached to PVC Pipe

Figure 6-8. Face of Connector Attached to PVC Pipe

The screws ensure that the connector will not freely spin in the PVC pipe. Figure 6-9 shows the rubber connector that tightly fits the head of the generator and the PVC pipe.

Figure 6-9. Rubber Connection that Integrates Generator and Connector

The flexibility of the rubber compensates for unsymmetrical rotation of the connector while attached to the generator. This ensures that the generator and the induction motor will not be damaged at high RPMs. Figure 6-10 shows the generator placed in its testing base board with the rubber coupling.

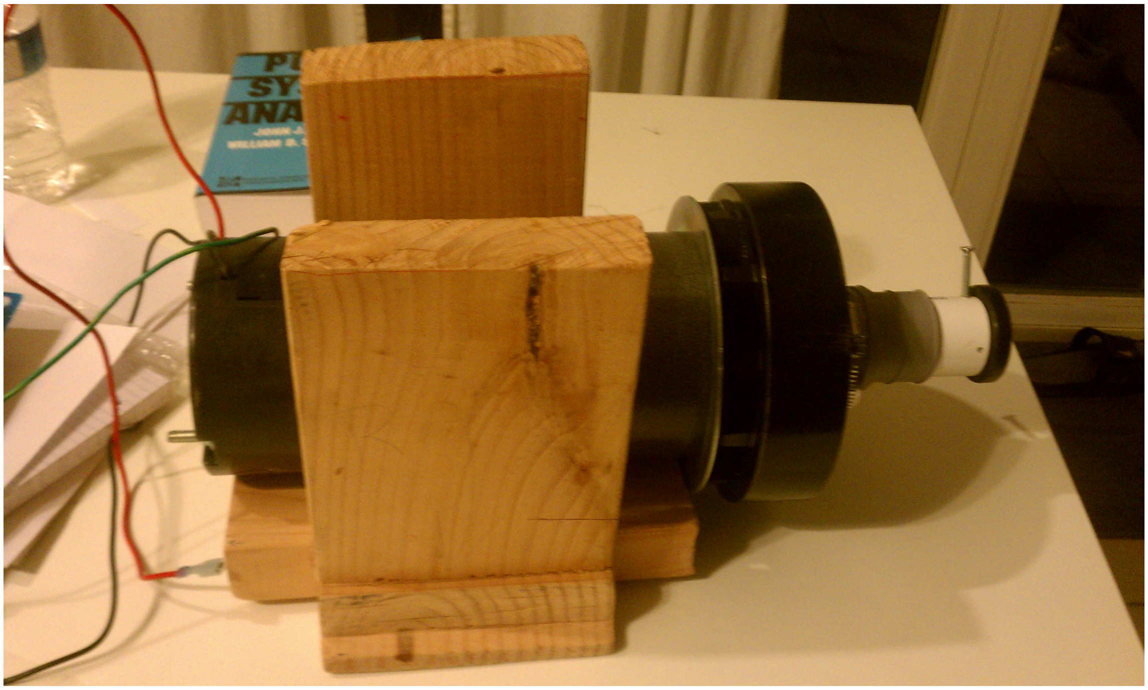

Figure 6-10. Generator on Stand

VII. Integration and Test Results

The first table displayed below shows the test results of the output voltage of our generator at various speeds in revolutions per minute. We used an induction motor to drive our DC generator. The ratings of our DC generator are 115V, 21.9A, at 4000RPM. Our theoretical voltages and efficiencies at a specific speed are calculated using the ratio (7-1) and equation (7-2).

$$4000\text{RPM} / 115\text{V} = 34.7826 \text{ RPM} / \text{V} \qquad (7\text{-}1)$$

$$[(\text{Theoretical} - \text{Actual}) / \text{Theoretical}] \times 100 = \%\text{Error} \qquad (7\text{-}2)$$

Table 7-1. Output Voltage of Generator at Various Speeds

RPM	Theoretical V_{out} [DC]	Actual V_{out} [DC]	% Error
102.00	2.93	2.78	5.20
160.00	4.60	4.33	5.87
201.00	5.78	5.47	5.34
255.00	7.33	6.92	5.61
300.00	8.63	8.13	5.74
351.00	10.09	9.53	5.56
390.00	11.21	10.55	5.91
440.00	12.65	11.92	5.77
505.00	14.52	13.70	5.64
544.00	15.64	14.74	5.75
592.00	17.02	16.10	5.41

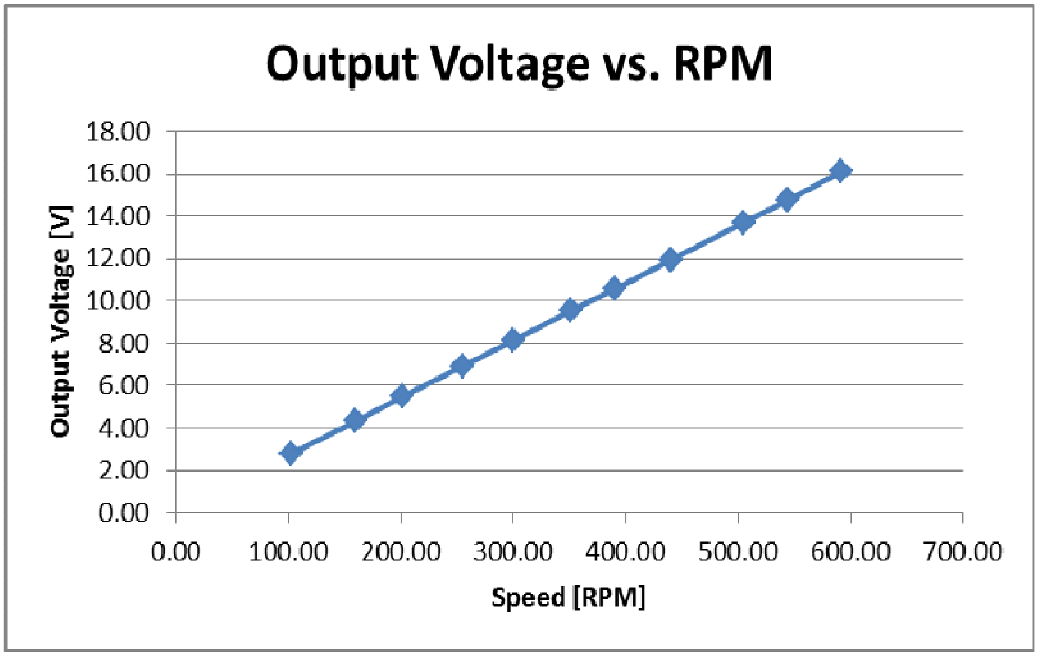

Figure 7-1. Generator Output Voltage at Various Speeds at No Load

Figure 7-1 shows the linear relationship between output voltage and generator speed. A quick analysis of Table 7-1 shows that the average percent error is around 5.5%. We expect a percent error that is low for our generator due to the mechanical resistance and the inefficiency of driving our generator with an induction motor. However, this is the best testing method in order to simulate the flow of water. The next test we implemented was testing the generator with the integration of the converter.

Table 7-2. Input and Output Voltages of the DC-DC Boost-converter at No Load

V_{in} [V]	V_{out} [V]
1.00	0.80
2.00	1.69
3.00	2.62
4.00	3.54
5.00	4.58
6.00	5.52
7.00	6.59
8.00	7.53
9.00	8.55
10.00	9.54
11.00	10.50
11.20	24.00
12.00	24.00
15.00	24.00
20.00	24.00
25.00	24.00
30.00	24.00

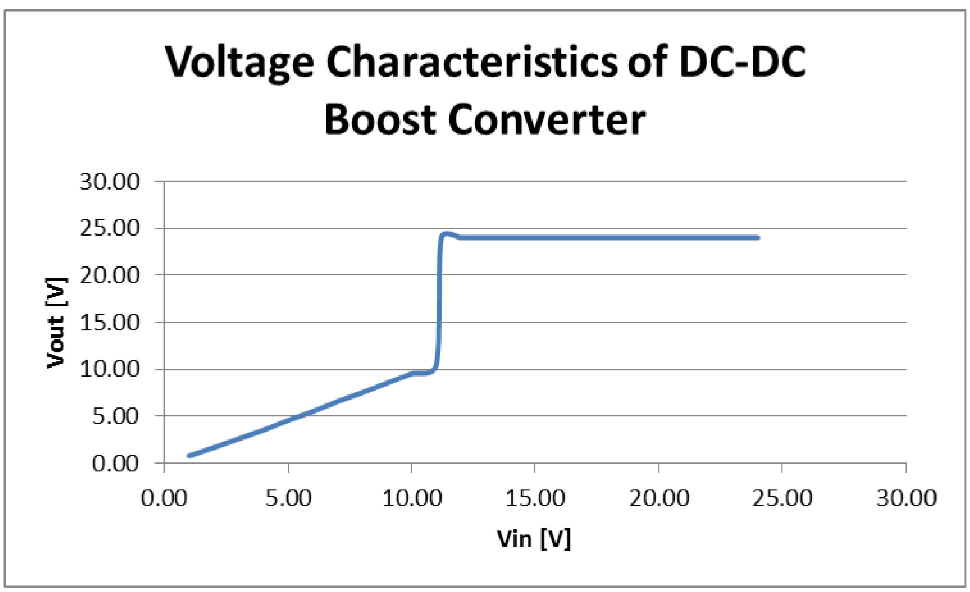

Figure 7-2. Voltage Characteristics of DC-DC Boost-converter at No Load

Table 7-2 and Figure 7-2 show the voltage characteristics of the DC-DC Boost-converter at no load. From Table 7-2, one can see that the converter boost's the input voltage by a factor of two once the input voltage is 11.2V. Once the converter has experienced an input voltage greater than 11.2V, the converter outputs a constant voltage regardless if the input voltage is beyond 24V as seen from the results in Table 7-2. This is what we expected from our converter. It is also important to note that once the converter has experienced 11.2V, the input voltage can drop down to 3.7V before the converter loses the ability to output a constant voltage of 24V. This information is crucial for our testing when we begin to test our overall system with various loads.

The next step is to test our converter with different loads to determine the converter's overall efficiency. The line and load regulations of the converter tell us the main characteristics of the system. The line regulation tells us how much change is expected when the input is uncertain, and the load regulation tells us the ability of the converter to maintain a 24V output even when the output power changes. Tables 7-3 and 7-4 shows the data collected from the converter to solve for its' voltage and line regulations using equations 7-3 and 7-4.

$$\textit{Voltage Regulation} = \frac{V_{out(low-load)} - V_{out(high-load)}}{V_{out(high-load)}} \quad (7\text{-}3)$$

Table 7-3. Voltage Regulation Data for DC-DC Boost-converter

V_{out}(high-load) [V]	V_{out}(low-load) [V]	Voltage Regulation [%]
22.06	24.26	9.97

$$\textit{Line Regulation} = \frac{V_{out(high-input)} - V_{out(low-input)}}{V_{out(nominal)}} \quad (7\text{-}4)$$

Table 7-4. Line Regulation Data for DC-DC Boost-converter

V_{out}(nominal) [V]	V_{out}(high-input) [V]	V_{out}(low-input) [V]	Line Regulation [%]
12	22.67	15.66	58.42

For our overall system tests, the boost-converter was made sure to be powered by increasing the RPM until the input voltage was 11.2V or greater. After powering the boost-converter, we lowered the RPM as much as possible but high enough such that the converter remains powered. We first collected data with our generator operating at 200 RPM. We believe that the generator will be spinning at this speed from flowing water. Full load of the overall system being used in Tables 7-5 to 7-9 is 200W at 24V.

Table 7-5. Data Taken of Overall System for Generator Operating at 200 RPM with Various Loads

V_{out} [V]	I_{out} [A]	% Load	V_{in} [V]	I_{in} [A]	P_{out} [W]	P_{in} [W]	% Efficiency
23.94	0.00	0.00	4.86	0.23	0.00	1.12	0.00
23.94	0.05	0.59	4.37	0.53	1.17	2.32	50.65
21.70	0.10	1.20	3.89	0.86	2.17	3.35	64.87
20.80	0.15	1.80	3.71	1.16	3.12	4.30	72.50
18.57	0.20	2.40	3.39	1.44	3.71	4.87	76.19
16.35	0.25	3.00	3.65	1.75	4.09	6.39	63.99

Table 7-5 shows the data collected from the overall system with the generator operating at 200 RPM. When the system becomes loaded at 1.2% of maximum load, the output voltage drops to 21.7V, which is out of specification of a constant output voltage of 24V. Hence, the input voltage is around 3.7V at 1.2% load, which explains why the output voltage drops below 24V. Around 3.7V, the boost-converter starts to lose its ability to boost the input voltage to its rated value. From the analysis of the data in Table 7-5, it indicates that the flow of water itself will not be enough to generate the specified output power.

Table 7-6. Data for Overall System with Generator Operating at 300 RPM with Various Loads

V_{out} [V]	I_{out} [A]	% Load	V_{in} [V]	I_{in} [A]	P_{out} [W]	P_{in} [W]	% Efficiency
23.94	0.00	0.00	7.77	0.18	0.00	1.40	0.00
23.94	0.10	1.20	7.22	0.52	2.39	3.75	63.77
23.93	0.15	1.80	6.88	0.73	3.59	5.02	71.47
23.92	0.20	2.40	6.87	0.91	4.78	6.25	76.52
23.91	0.25	3.00	6.58	1.15	5.98	7.57	78.99
23.90	0.30	3.60	6.26	1.42	7.17	8.89	80.66
23.88	0.40	4.80	5.40	2.26	9.55	12.20	78.27
23.89	0.50	6.00	5.05	3.08	11.95	15.55	76.80
23.30	0.60	7.20	4.55	3.88	13.98	17.65	79.19
21.60	0.65	7.80	4.30	4.18	14.04	17.97	78.11

Table 7-6 shows the data collected from the overall system with the generator operating at 300 RPM. When the system is first loaded at 1.2% of maximum load, the output voltage is close to 24V. As the load increases, the output voltage decreases slightly, but stays relatively close to 24V. When the system is loaded at around 7.8% of maximum load the output voltage drop to 21.60V.

Table 7-7. Data for Overall System with Generator Operating at 400 RPM with Various Loads

V_{out} [V]	I_{out} [A]	% Load	V_{in} [V]	I_{in} [A]	P_{out} [W]	P_{in} [W]	% Efficiency
23.94	0.00	0.00	10.50	0.02	0.00	0.25	0.00
23.95	0.10	1.20	10.15	0.39	2.40	3.92	61.13
23.93	0.20	2.40	9.70	0.66	4.79	6.36	75.21
23.92	0.30	3.60	9.24	0.96	7.18	8.88	80.81
23.90	0.40	4.80	8.85	1.29	9.56	11.45	83.48
23.87	0.60	7.20	8.50	1.96	14.32	16.66	85.97
23.85	0.70	8.40	8.09	2.41	16.70	19.51	85.56
23.80	0.90	10.79	6.55	5.00	21.42	32.75	65.40
23.70	1.01	12.11	6.10	5.80	23.94	35.38	67.66
23.62	1.10	13.19	5.24	6.88	25.98	36.05	72.07
21.97	1.20	14.39	5.08	7.48	26.36	38.00	69.38
19.47	1.30	15.59	4.74	8.05	25.31	38.16	66.33
16.55	1.40	16.79	4.33	8.63	23.17	37.37	62.01
15.20	1.50	17.99	4.20	9.23	22.80	38.77	58.81

Table 7-7 shows the data collected from the overall system with the generator operating at 400 RPM. When the system is first loaded at 1.2% of maximum load, the output voltage is close to 24V. As the load increases, the output voltage decreases slightly, but again stays relatively close to 24V. When the system is loaded at around 14.39% of maximum load does the output voltage drop to 21.97V.

Table 7-8. Data for Overall System with Generator Operating at 500 RPM with Various Loads

V_{out} [V]	I_{out} [A]	% Load	V_{in} [V]	I_{in} [A]	P_{out} [W]	P_{in} [W]	% Efficiency
23.98	0.00	0.00	13.21	0.12	0.00	1.52	0.00
23.96	0.10	1.20	12.80	0.31	2.40	3.96	60.58
23.95	0.20	2.40	12.43	0.51	4.79	6.38	75.12
23.91	0.40	4.80	12.08	0.94	9.56	11.36	84.23
23.88	0.60	7.20	11.49	1.43	14.33	16.38	87.45
23.85	0.80	9.59	10.97	1.97	19.08	21.57	88.47
23.82	1.00	11.99	10.85	2.47	23.82	26.80	88.88
23.80	1.20	14.39	10.53	3.08	28.56	32.40	88.15
23.76	1.40	16.79	9.80	3.90	33.26	38.22	87.03
23.60	1.60	19.19	6.90	9.10	37.76	62.79	60.14
22.20	1.80	21.59	5.71	11.00	39.96	62.81	63.62

Table 7-8 shows the data collected from the overall system with the generator operating at 500 RPM. As the load increases, the output voltage decreases slightly, but stays relatively close to 24V. When the system is loaded at around 21.59% of maximum load does the output voltage drop to around 22.2V.

Table 7-9. Data for Overall System with Generator Operating at 600 RPM with Various Loads

V_{out} [V]	I_{out} [A]	% Load	V_{in} [V]	I_{in} [A]	P_{out} [W]	P_{in} [W]	% Efficiency
24.00	0.00	0.00	16.17	0.09	0.00	1.46	0.00
23.94	0.25	3.00	15.38	0.49	5.99	7.54	79.42
23.90	0.50	6.00	14.78	0.93	11.95	13.75	86.94
23.86	0.75	9.00	14.23	1.40	17.90	19.92	89.83
23.81	1.00	12.0	13.70	1.92	23.81	26.30	90.52
23.77	1.25	15.0	13.71	2.39	29.71	32.77	90.68
23.73	1.50	18.0	13.17	2.99	35.60	39.38	90.39
23.68	1.75	21.0	12.65	3.64	41.44	46.05	90.00
23.63	2.00	24.0	12.52	4.21	47.26	52.71	89.66
9.90	2.50	30.0	5.83	7.40	24.75	43.14	57.37

Table 7-9 shows the data collected from the overall system with the generator operating at 600 RPM. When the system is first loaded at 3% of maximum load, the output voltage is close to 24V. As the load increases, the output voltage decreases slightly, but stays relatively close to 24V. Only until the system is loaded at around 30% of maximum load does the output voltage drop to 9.9V.

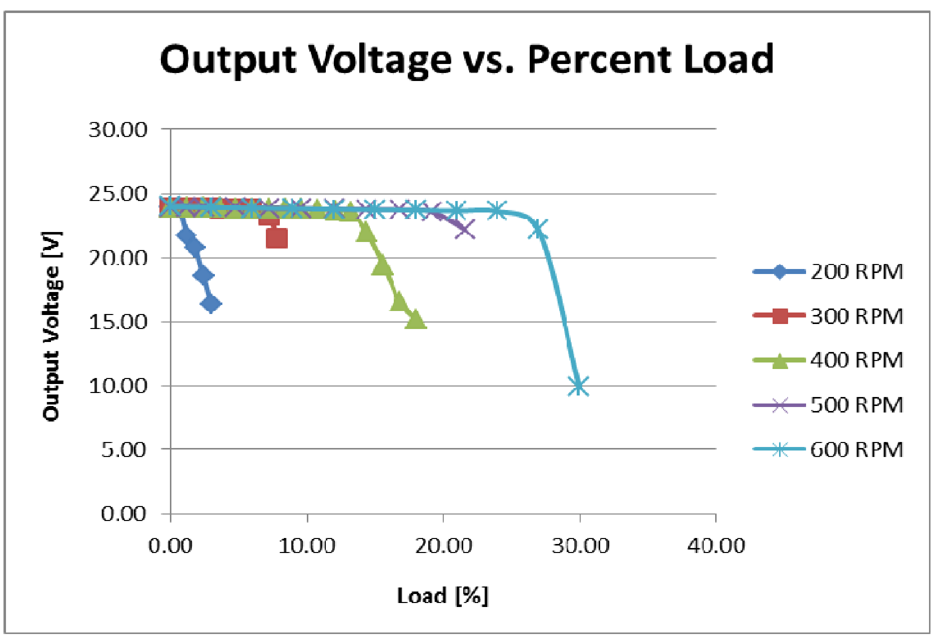

Figure 7-3. Output Voltage vs. Percent Load at Various RPMs

From Figure 7-3, it can be seen that at higher RPMs, the output voltage of 24V can be maintained longer as the load increases. The reason for this is because the generator cannot withstand the increase in load at lower RPMs. As the load increases at a given RPM, the generator starts to lose its ability to output the voltage required to the boost-converter in order to boost the input voltage.

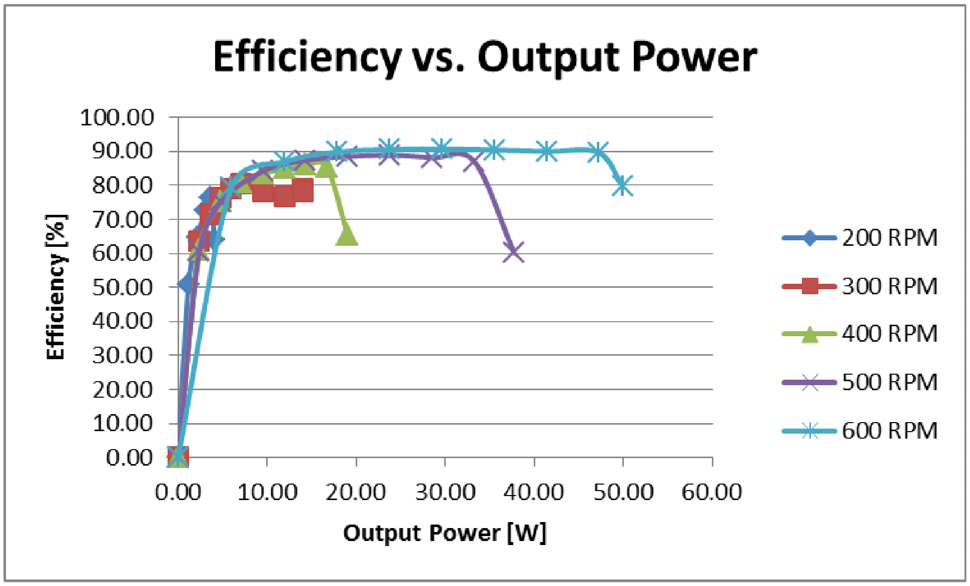

Figure 7-4. Efficiency of System vs. Output Power at Various Speeds

Figure 7-4 shows the efficiency of the overall system versus output power from 200-600 RPM. At higher RPM, the system can maintain high efficiency as output power increases. Even though the specified output power is not met, an efficient system can still be designed.

VIII. Conclusion

This project presents a solution to power access for people in secluded or remote places with the harnessing of energy from flowing water with a turbine and motor. From Tables 3-6, it can be concluded that the maximum output power of the overall system from our tests is only 47.26W. This maximum output power is only produced at specifically, 600 RPM. We believe that the flow of water is equivalent to only around 200 RPM. The power produced is well below the specification of the project of 200-300W. The following provides suggestions on how to increase the output power.

In order to produce much more output power, we suggest the design and use of mechanical gears or a dam system to funnel the flow of water to increase the RPM of our motor. Mechanical gears can artificially create more turns per minute, and as a result produce more power. Our limited knowledge with gear design and integration prevents us from using gears. A properly designed dam system can use the force of gravity to increase the flow of water and in turn produce a higher RPM. The time, knowledge, and tools necessary for building a dam system are unavailable. A better suggestion is to use a more efficient generator that has a lower RPM to power ratio. The chances are that a generator that meets the output power specifications will be larger and more expensive.

The overall system requires three major components: a turbine, generator, and DC-DC Boost-converter. These main components cost around $370. Table 8-1 shows the breakdown for the overall cost of the project.

Table 8-1. Parts List and Cost of Each Part

Part	Cost ($)
DC Motor	110.00
Pelton Turbine	70.00
DC-DC Boost-converter	189.00
2x4x6 Wood	7.00
x6 2.5" Wood Screws	2.99
PVC	0.99
Rubber PVC Connector	1.99
Total	381.97

The main problem that we encountered while conducting this project was insufficient power generation. The generator did not have a low enough RPM to power ratio, and as a result, could not withstand much loading as shown in Table 7-9. Although the boost-converter worked as expected, the low power output of the generator was not sufficient enough to meet the specified output power of 200-300W. Other problems occurred in the process of designing the base board and the coupler to test our generator. It was difficult to align and couple the armatures of our generator to the induction motor.

The difficulty of harnessing sustainable energy is proven through this project. Most of the problems we encountered should be eliminated in the next phase because our research showed that with the proper equipment, a system can output 200-300W. The components that we selected were not capable of meeting these requirements. Our resulting system can be used to contribute to the grid of the DC House, but is very limited.

IX. Bibliography

[1] The NEED Project. [Online] Available: http://www.need.org/needpdf/infobook_activities/SecInfo/HydroS.pdf

[2] Mary Bellis (1997). *Michael Faraday.* [Online] Available: http://inventors.about.com/library/inventors/blfaraday.htm

[3] Nathanial Gronewold. (2009, November 24). *One-Quarter of World's Population Lacks Electricity.* [Online] Available: http://www.scientificamerican.com/article.cfm?id=electricity-gap-developing-countries-energy-wood-charcoal

[4] Taufik. (2010, September 13). *The DC House Project*. [Online] Available: http://www.calpoly.edu/~taufik/dchouse/index.html

[5] Wikipedia. (2011, March 19). [Online] Available: http://en.wikipedia.org/wiki/Hydroelectricity

FIGURE REFERENCES

[1-1] http://www.renewable-solarenergy.com/img/what-are-how-renewable-energy-sources-works.jpg

[1-2] http://gizzisgoodies.wikispaces.com/file/view/irrigation.jpg/164937109/irrigation.jpg

[1-3] http://www.top-alternative-energy-sources.com/images/water-wheel-horiz400x350.jpg

[1-4] http://www.ssplprints.com/lowres/43/main/18/97330.jpg

[1-5] http://energysources0.tripod.com/sitebuildercontent/sitebuilderpictures/hydro-electricdam.gif

[1-6] http://www.greenrightnow.com/wp-content/uploads/pie_chart_fuel_mix.gif

[4-1] http://www.daviddarling.info/encyclopedia/W/AE_water_turbine.html

[4-2] http://hsc.csu.edu.au/physics/core/motors/2696/generatorDC.gif

[4-3] http://en.wikipedia.org/wiki/File:Boost_conventions.svg

[4-5] http://cgi.ebay.com/ws/eBayISAPI.dll?VISuperSize&item=300551193470

[4-6] http://en.wikipedia.org/wiki/File:Pelton_wheel_%28patent%29.png

[4-7] http://en.wikipedia.org/wiki/File:Walchenseewerk_Pelton_120.jpg

[4-13] http://zahninc.com/2448600install.html

[4-15] http://www.minihidraulica.com/fotos/minihidraulica/microhydro.jp

APPENDICES

A. Time Estimates/Allocations

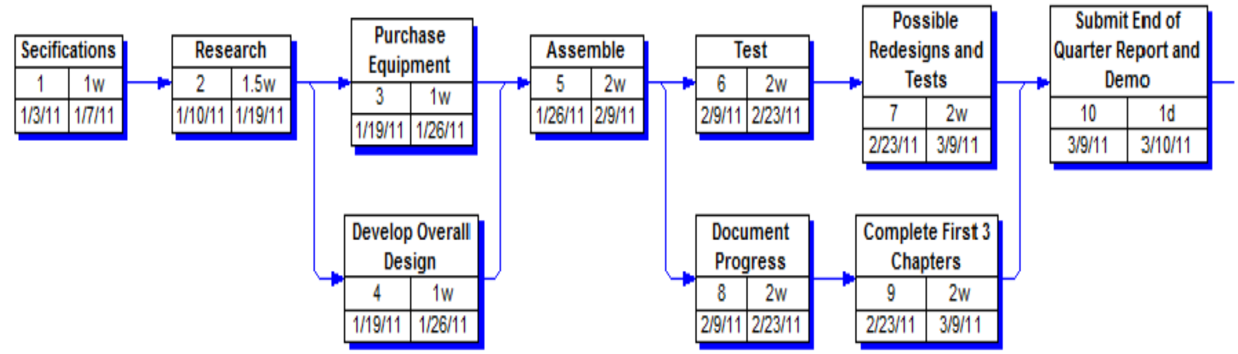

Figure A-1. Winter 2011 Project Schedule

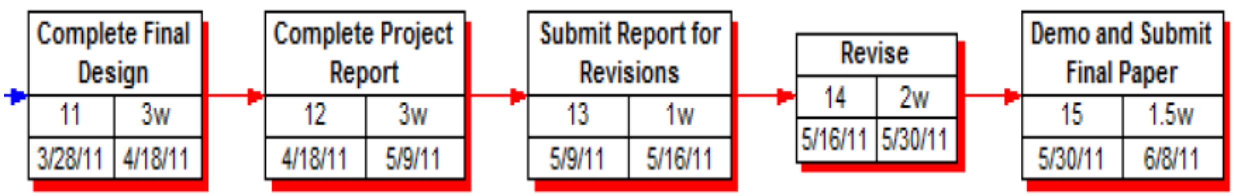

Figure A-2. Spring 2011 Project Schedule

Table A-1. Time Allocations for Different Tasks

Task	Hours Required	Description
Research	50	Online and textbook research
Design	35	Consider different design options
Construction	20	Build compatible testing equipment
Testing	30	Test system inputs and outputs